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Strategy Development for Corrosion Problem in Geothermal Installations Based on Corrosion Management Technology

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ABSTRACT

Major concern for geothermal installations is the prevention of major incidents resulting from failure of safety-critical elements. Addressing this hazard requires an understanding of failure modes and use of industry standard procedures for the assessment and control of risks. Corrosion related failures of processing facilities are a major source of risk to geothermal industry installations. Corrosion can be a life-limiting cause of deterioration by general wastage, and/or pitting and/or environmentally assisted cracking to plant items which in turn can lead to loss of containment of process fluids. Most practices and procedures employed for the control of corrosion in geothermal facilities involves proven technology that is generally accepted world wide. These can be considered as the tactical aspects or corrosion control options: material selection, chemical treatments, use of coating, cathodic protection, process and environmental control, and design. These options are used either of singly or in combination, where the choice depends on the specific application and the corrosivity of local environments.

Engineering success requires selection of the most viable options, both technical and economic, then, by means of corrosion inspection and monitoring, combined with suitable maintenance strategies and procedures ensure that the life cycle objectives are achieved as integrated in Corrosion Management Technology. In practice, there is a need to improve the feedback from operational experience to future designs. The practical means of achieving specified objectives (minimum leakage and downtime, lowest life cycle costs) requires guidelines, codes and standards for specification of the works (the tactics) plus suitable management procedures and systems (the strategic means).

1. INTRODUCTION

The industry recognizes that corrosion is a vital issue for the safety of geothermal installations. Corrosion can adversely affect integrity and therefore operators include corrosion mitigation and inspection procedures as a part of their safety case and as a requirement for meeting the design and construction regulations. The aim of the verification scheme is to improve safety standards throughout the installations life cycle, from design to fabrication/construction and hook-up through the whole operating life. The duty holder (through legally delegated representatives) must therefore continuously identify hazards at each stage, assess risks and develop suitable management system for measurement of performance and reporting. The independent verifier provides the essential audit or safety check. In principle the audit would include determination of the condition of hardware and the management processes employed to ensure continuing integrity.

In practice, there is a need to improve the feedback from operational experience to future designs. This could be achieved by provision of a direct input into engineering projects from operational personnel or ensuring that audits of designs and fabrication procedures are conducted by experienced site engineers. It is in strategy development for corrosion mitigation that difficulties often appear. Particular areas of concern are the overall management of corrosion risks, the effective deployment of human resources and the development of appropriate organizational structures and systems to meet changing situations. The practical means of achieving specified objectives requires guidelines, codes and standards for specification of the works plus suitable management procedures and systems.

2. CORROSION OVERVIEW

The most accepted definition for corrosion is the destruction of material due to a chemical reaction of the material with its environment. Generally, this destruction takes place on its surface in the form of material dissolution or re-deposition in some other form. Metallic systems are the predominant materials of construction, and as a class, are generally susceptible to corrosion. Consequently, the bulk of corrosion science focuses upon metals and alloys. Corrosion will occur when four main factors of corrosion meet in one time. The four main factors are Cathode, Anode, Electrolyte and Electric. Corrosion consists of an oxidation reaction and a reduction reaction at the surface of the corroding material. The oxidation reaction generates metal ions and electrons; the electrons are then consumed in the reduction reaction. For environments with water present including moisture in the air, the electrons are consumed by converting oxygen and water to hydroxide ions. In iron and many iron alloys, these hydroxide ions in-turn combine with iron ions to form a hydrated oxide ($Fe(OH)_2$). Subsequent reactions form a mix of magnetite (Fe_3O_4) and hematite (Fe_2O_3). This red-brown mixture of iron oxides is rust. Figure 1, illustrates the basic oxidation/reduction reaction behind corrosion.

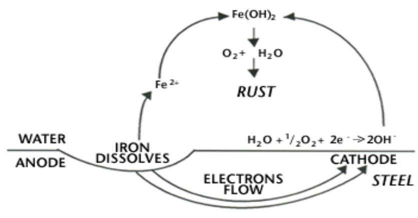

Figure 1: Electrochemical Process

The higher the ionic conductivity, the quicker this reaction takes place. This is why water containing electrolytes, such as salt, is far more damaging. Another key point to note is that reducing the amount of dissolved oxygen in solution directly can inhibit corrosion. However, many other reduction reactions can consume the electrons.

2.1 Causes of Corrosion

All engineering materials are reactive chemically and that the strength of materials depends totally upon the extent to which environments influence the reactivity and subsequent degradation of these materials. In order to define the strength of an engineering material for a corrosion based design it is essential to define the nature of the environments affecting the material over time, i.e:

Material factor

a. Chemical composition
b. Microstructure
c. Grain boundary composition
d. Surface condition

Environment Factor

a. Nominal environment definition (type, chemistry, concentration, phase and conductivity)
b. Local environment definition (velocity, thin layer wetting, wetting and drying cycles, heat transfer boiling, wear and fretting, and deposits)

Stress Factor

a. Stress definition (mean stress, maximum stress, minimum stress, constant load/constant strain, strain rate, plane stress/plane strain, biaxial, cyclic frequency and wave shape)
b. Sources of stress (intentional, residual, corrosion wedging and thermal cycling)

Geometry Factor

a. Discontinuities which intensify stress
b. Generation of galvanic potentials
c. Chemical
d. Settling of solids
e. Restricted geometries leading to concentration cells

Temperature and Pressure Factors

Time Factor

a. Changes in GB chemistry
b. Changes in microstructure
c. Changes in surface deposits, chemistry or/and heat transfer resistance
d. Development of surface defects, pitting or/and erosion
e. Development of occluded cells

2.2 Corrosion Forms and Mechanisms

Corrosion has five teen different forms but only one, uniform attack, lends itself to accurate life prediction based upon knowledge of the intended environment. The remaining fourteen forms are insidious with the actual corrosion damage being localized. The result is that component failure can be unexpected or premature. A discussion on each of the five teen forms of corrosion is listed below. Performing an analysis on the potential for a component/structure to corrode involves an assessment on whether any of these corrosion mechanisms could be applicable based upon the material in question and the intended environment.

<u>2.2.1 Uniform (General) Attack</u>

Uniform attack occurs evenly over the entire surface. The rate of corrosion is often presented as a weight loss. Uniform corrosion is very predictable, and is the basis of most corrosion prediction equations. Corrosion occurring at the same rate over much of the surface area is considered a uniform or general corrosion. General overall corrosion is not too great a concern because it can be predicted and proper materials selection and the use of adherent coatings can preclude this particular corrosion mechanism from occurring. However, uniform corrosion will rapidly attack corrosion sensitive materials should the coating become nicked or scratched.

<u>2.2.2 Bimetallic Corrosion</u>

Bimetallic corrosion will occur when two different are placed in contact in an electrolyte containing an oxidizing agent, the more reactive one will corrode and other will not. This coupling of dissimilar metals is referred to as a bimetallic couple. It can be extremely destructive, drastically accelerating the corrosion rate of the more reactive of two metals.

<u>2.2.3 Crevice Corrosion</u>

Corrosion that occurs next to or inside a tightly occluded area is referred to as crevice corrosion. In another word, is a localized form of corrosion which occurs within the stagnant zones created by the interfaces between two surfaces. This form of corrosion occurs when a liquid corrosive is trapped in a gap between two components, in which at least one is sensitive to this form of corrosion. The gap must be sufficiently narrow (< 1/8 inch) to maintain a stagnation zone. Once this zone is established, the concentration of the corrosive increases as the corrosion reaction takes place. There is a long incubation process, from six months to a year, before the reaction commences. However, after initiation the reaction proceeds at a continuously increasing rate. Metals and alloys that rely upon oxide films or passive layers, such as stainless steels, for corrosion resistance are particularly susceptible to crevice corrosion. Crevice corrosion can also occur under washers, gaskets, debonded coatings, surface deposits, sealing rings, rivets, sleeves, surface scale, switch contacts, clamps, etc.

- *Filiform corrosion:* corrosion that occurs under some coatings in the form of randomly distributed threadlike filaments.
- *Pack rust:* this particular form of corrosion is often used in relation to bridge inspection to describe built-up members) of steel bridges which are already showing signs of rust packing between steel plates.

<u>2.2.4 Pitting</u>

Pitting corrosion is a localized form of corrosion that proceeds with minimal overall metal loss, or corrosion that has the appearance of pin holes or cavities is referred to as pitting corrosion. This form of corrosion is very destructive since it can cause failure with only a small percent weight loss of the actual structure. The pits themselves are actually cavities with a diameter that is less than or equal to its depth. The pits can grow to such a depth that they perforate the component in question. Failures resulting from pitting corrosion are almost entirely caused by chloride and chlorine containing ions. Stainless steels are more susceptible to this form of corrosion than any other class of metals or alloys.

<u>2.2.5 Galvanic Corrosion</u>

Corrosion caused by an electrochemical reaction between two dissimilar metals when placed in contact or electrically connected with each other in an electrolyte. Tables displaying the Galvanic Series of selected commercial metals and alloys in seawater are readily available and may be used to judge the relative sensitivity dissimilar metals and alloys have towards galvanic corrosion. In general, materials at the top of the list (e.g., gold, titanium and silver) are corrosion resistant while those at the bottom (aluminum, zinc and magnesium) are not. Additionally, when two different metals or alloys come in contact with each other, the one that is closest to the top of the table is cathodically protected while the one closest to the bottom becomes anodic and as a result, corrodes. Metals that are listed near each other on the table show far less sensitivity to galvanic corrosion than those that are far apart.

2.2.6 Lamellar Corrosion

Lamellar corrosion is a form of corrosion in which the expanding corrosion products stack up as layers. Corrosion that proceed laterally from the sites of initiation along planes parallel to the surface, generally at grain boundaries, forming corrosion products that force metal way from the body of the material, giving it a layered appearance. It also indicates that it is synonymous to 'lamellar corrosion'. Similar to exfoliation of high strength aluminum alloys, exfoliation affects primarily aluminum alloys, attack proceeding laterally from initiation sites on the surface and generally proceeding intergranularly along planes parallel to surface.

2.2.7 Erosion Corrosion

This form of corrosion results when there is movement of one medium adjacent to another that removes the protective material such as surface oxide coating. The moving mediums can be a liquid or slurry such as fluid flow through a pipe. An action involves both corrosion and erosion in the presence of a moving corrosive fluid leading to the accelerated loss of material. The second form of erosion corrosion is fretting corrosion that occurs by movement of the contact region between two solid materials. This form of corrosion can be induced by vibration or by thermally induced expansion and contraction of materials with different coefficients of expansion.

2.2.8 Cavitation Erosion

Cavitation occurs when a fluid's operational pressure drops below it's vapor pressure causing gas pockets and bubbles to form and collapse. This can occur in what can be a rather explosive and dramatic fashion. In fact, this can actually produce steam at the suction of a pump in a matter of minutes. When a process fluid is supposed to be water in the 20-35°C range, this is entirely unacceptable. Additionally, this condition can form an airlock, which prevents any incoming fluid from offering cooling effects, further exacerbating the problem.

The locations where this is most likely to occur, such as:

- at the suction of a pump, especially if operating near the net positive suction head required.
- at the discharge of a valve or regulator, especially when operating in a near-closed position.
- at other geometry-affected flow areas such as pipe elbows and expansions.
- also, by processes incurring sudden expansion, which can lead to dramatic pressure drops.

This form of corrosion will eat out the volutes and impellers of centrifugal pumps with ultrapure water as the fluid. It will eat valve seats. It will contribute to other forms of erosion corrosion, such as found in elbows and tees. Cavitation should be designed out by reducing hydrodynamic pressure gradients and designing to avoid pressure drops below the vapor pressure of the liquid and air ingress. The use of resilient coatings and cathodic protection can also be considered as supplementary control methods.

2.2.9 Fretting Corrosion

Fretting corrosion refers to corrosion damage at the asperities of contact surfaces. This damage is induced under load and in the presence of repeated relative surface motion, as induced for example by vibration. Pits or grooves and oxide debris characterize this damage, typically found in machinery, bolted assemblies and ball or roller bearings. Contact surfaces exposed to vibration during transportation are exposed to the risk of fretting corrosion. Damage can occur at the interface of two highly loaded surfaces which are not designed to move against each other. The most common type of fretting is caused by vibration. The protective film on the metal surfaces is removed by the rubbing action and exposes fresh, active metal to the corrosive action of the atmosphere

2.2.10 Intergranular Corrosion

This phenomenon occurs preferentially at grain boundaries, usually with slight or negligible attack on the adjacent grains. Three different factors can make an alloy susceptible to this type of corrosion. These factors include impurities at the grain boundaries, enrichment of one of the alloying elements, or depletion of one of these elements in the grain boundary area. Intergranular corrosion occurs when the impurities along the grain boundaries are removed as a result of the corrosive environment. The result is that the individual grains not tightly bonded together fail along the grain boundary with little applied stress. Intergranular corrosion can occur through the grains.

2.2.11 Exfoliation

Exfoliation corrosion is a particular form of intergranular corrosion associated with high strength aluminum alloys. Alloys that have been extruded or otherwise worked heavily, with a microstructure of elongated, flattened grains, are particularly prone to this damage. Corrosion products building up along these grain boundaries exert pressure between the grains and the end result is a lifting or leafing effect. The damage often initiates at end grains encountered in machined edges, holes or grooves and can subsequently progress through an entire section.

2.2.12 Dealloying (Selective Leaching)

One element is preferentially removed from an alloy, leaving a residue (often porous) of the elements that are more resistant to the particular environment. It is also called de-alloying or parting. This form of corrosion results when one element from a solid alloy is removed through a corrosion process. The most common example is when zinc is removed from brass alloys. Other elements that can experience similar processes include aluminum, iron, cobalt, and chromium. These elements can be removed when the alloys containing them are exposed to aqueous acids. Common forms of selective leaching are decarburization, decobaltification, denickelification, dezincification, and graphitic corrosion.

2.2.13 Corrosion Fatigue

Corrosion-fatigue is the result of the combined action of an alternating stress and a corrosive environment. The fatigue process is thought to cause rupture of the protective passive film, upon which corrosion is accelerated. The introduction of a corrosive environment often eliminates the normal "fatigue" limit of a ferrous alloy, thereby creating a finite life regardless of stress level. The corrosive environment can cause a faster crack growth and/or crack growth at a lower tension level than in dry air. Even relatively mild corrosive atmospheres can reduce the fatigues strength of aluminum structures considerably, down to 75 to 25% of the fatigue strength in dry air. No metal is immune from some reduction of its resistance to cyclic stressing if the metal is in a corrosive environment. Control of corrosion fatigue can be accomplished by either lowering the cyclic stresses or by corrosion control.

2.2.14 Hydrogen Embrittlement

This is a type of deterioration which can be linked to corrosion and corrosion-control processes. It involves the ingress of hydrogen into a component, an event that can seriously reduce the ductility and load-bearing capacity, cause cracking and catastrophic brittle failures at stresses below the yield stress of susceptible materials. Hydrogen embrittlement occurs in a number of forms but the common features are an applied tensile stress and hydrogen dissolved in the metal. Examples of hydrogen embrittlement are cracking of weldments or hardened steels when exposed to conditions which inject hydrogen into the component. Presently this phenomenon is not completely understood and hydrogen embrittlement detection, in particular, seems to be one of the most difficult aspects of the problem. Hydrogen embrittlement does not affect all metallic materials equally. The most vulnerable are high-strength steels, titanium alloys and aluminum alloys.

Sources of hydrogen causing embrittlement have been encountered in the making of steel, in processing parts, in welding, in storage or containment of hydrogen gas, and related to hydrogen as a contaminant in the environment that is often a by-product of general corrosion. It is the latter that concerns the nuclear industry. Hydrogen may be produced by corrosion reactions such as rusting, cathodic protection, and electroplating. Hydrogen may also be added to reactor coolant to remove oxygen from reactor coolant systems. Hydrogen entry, the obvious pre-requisite of embrittlement, can be facilitated in a number of ways summarized below:

a. by some manufacturing operations such as welding, electroplating, phosphating and pickling; if a material subject to such operations is susceptible to hydrogen embrittlement then a final, baking heat treatment to expel any hydrogen is employed.
b. as a by-product of a corrosion reaction such as in circumstances when the hydrogen production reaction acts as the cathodic reaction since some of the hydrogen produced may enter the metal in atomic form rather than be all evolved as a gas into the surrounding environment. In this situation, cracking failures can often be thought of as a type of stress corrosion cracking. If the presence of hydrogen sulfide causes entry of hydrogen into the component, the cracking phenomenon is often termed sulphide stress cracking.
c. the use of cathodic protection for corrosion protection if the process is not properly controlled.

2.2.15 Stress Corrosion

Stress corrosion requires the material in question to be under a tensile stress and also to be exposed to an environment that will initiate cracks within the stressed part. The stress can be as low as 10% of the yield stress for certain alloys and up to 70% for others. Loads applied by mounting bolts, in-service conditions, or even manufacturing processes such as welding can induce stress corrosion. Furthermore, stress corrosion induced by the joint influence of mechanical stress and corrosion processes. Static-tensile stress causes stress corrosion cracking (SCC). The stresses initiating SCC damage are in the form of applied mechanical stress or residual stress. Manufacturing processes such as welding, bending, cold deformation (cold working), or electroplating of metallic components can bring about residual stresses. Differences in the coefficients of thermal expansion (CTE) of the materials in contact increase the risk of SCC. Corrosion fatigue is often considered to be a form of SCC. Cyclic loading brings about corrosion fatigue. Usually, most of the surface remains unattacked, but with fine cracks penetrating into the material. In the microstructure, these cracks can have an intergranular or a transgranular morphology. Macroscopically, SCC fractures have a brittle appearance. SCC is classified as a catastrophic form of corrosion, as the detection of such fine cracks can be very difficult and the damage not easily predicted. Experimental SCC data is notorious for a wide range of scatter. A disastrous failure may occur unexpectedly, with minimal overall material loss.

The corrosion of iron illustrates that many reactions can occur. Similar to iron, aluminum forms an oxide scale; however, the oxide scale formed (alumina) is cohesive, adherent and inhibits further corrosion. The oxide film formed ennobles the metal and reduces electrical current density by as much as six orders of magnitude. Materials like aluminum exhibit three corrosion regions:

a. Active Region - Increases in the oxidation potential lead to increasing corrosion rates. This region corresponds to the beginning of corrosion.
b. Passive Region - Increasing the oxidation potential past the active region reduces the corrosion rate.
c. Transpassive Region - Increasing the oxidation potential past the passive region, increases corrosion rate.

If the oxidizing potential is raised to high enough levels the oxide film breaks down and the material begins to actively corrode again. Given the many reactions that can occur and the corrosion regions possible, accelerating the corrosion process is difficult without altering the corrosion mechanism. Categorizing corrosion forms into specific groups is not straightforward, because such groups have overlapping characteristics, which influence the initiation and propagation of corrosion. However, corrosion is often categorized by how it manifests itself, as described in Corrosion Mechanisms above.

2.3 Classes of Corrosion

ASM offers a classification of corrosion that can be useful for designers. This classification, shown in Table A (see Appendix), categorizes various corrosion processes by mechanism of attack. Inspection of this table indicates that some forms of corrosion affect (relatively) large areas as indicated in the section addressing "General Corrosion" while other mechanisms are very local in nature. Other corrosion mechanisms are facilitated by metallurgical factors while still others rely upon the movement of two structures relative to each other or a structure or component subjected to moving fluids or slurries. The final category identifies corrosion mechanisms that result from the inspection of a "stressed" material in the presence of a corrosive agent. Some of these mechanisms can be easily dealt with or mitigated through proper design and materials selection decisions.

Group 1 - readily identifiable by ordinary visual examination.

a. Uniform corrosion
b. Crevice corrosion (filiform corrosion and pack rust)
c. Pitting
d. Galvanic corrosion
e. Lamellar corrosion

Group 2 - may require supplementary means of examination

a. Erosion corrosion
b. Cavitation
c. Fretting corrosion

d. Intergranular corrosion
e. Exfoliation
f. Dealloying (selective leaching)

Group 3 - verification is usually required by microscopy (optical, electron microscopy etc.)

a. Corrosion fatigue
b. Hydrogen embrittlement
c. Stress Corrosion Cracking (SCC)

3. CORROSION MANAGEMENT TECHNOLOGY

Corrosion Management Technology is the integrated efforts to achieve the technique and method for handling of the corrosion problems based on the Corrosion Management and Risk Management Analysis with adopting the optimal and efficient technology. Target of this system are to integrated decision tools, reliability strategy to perform capital rationing, and life cycle planning as integrated enabling tool into performance management. Corrosion Management Technology is an advance of corrosion management system, which consists of risk management analysis system. On the other hand, Corrosion Management Technology has a progressive framework that is compatible with the requirements of risk, safety and reliability management system concerned with ensuring the integrity of operating and processing equipments, as illustrated in Figure 1.

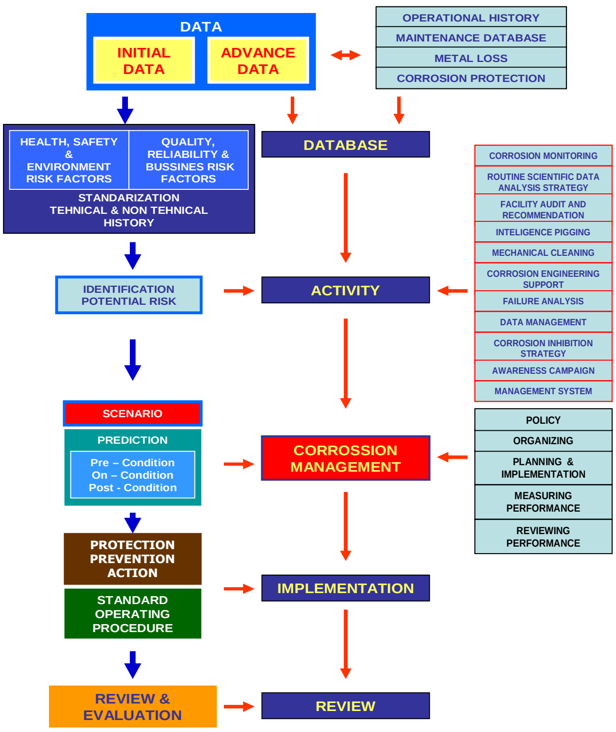

Figure 1: Corrosion Management Technology Framework

Corrosion problems in geothermal installations can be eliminating and predicting for production, processing and plant facilities which area of interest in design, installation, operation and maintenance. As the integrity management process also covers other integrity risks and causes of failure and damage that may occurred hazards. The policy that made will provide a structured framework for identification of risks associated with corrosion, and the development performance operating system including corrective actions with the target are optimization and efficiency for geothermal industries. Additional techniques that will conduct in this system are:

- optimum potential risk mapping,
- optimum operational and maintenance strategy,
- optimum safety management strategy,
- optimum engineering strategy and spare part inventory,
- optimum project management system,
- optimum inspection and monitoring system,
- optimum investigation system and corrective action,
- computerized operational and maintenance management system,
- operator activity management system,
- configuration management and contract management systems.

The corrosion management technology mapping is shown in Figure 2, respectively.

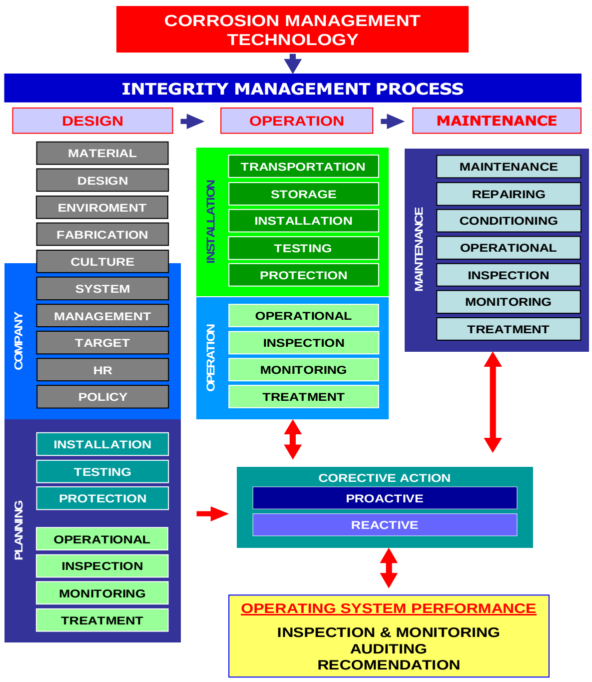

Figure 2: Corrosion Management Technology Mapping

3.1 Corrosion Management

The function of the Corrosion Management is a part of policy making in order to handle the corrosion problems, including development, implementation, review and maintenance. In the operation of a geothermal industry, the management of corrosion lies within the function of many parts of the duty holder's organization. It is therefore important that corrosion management activities are carried out within a structured framework that visible, understood by all parties and where roles and responsibilities are clearly defined.

A structured approach such as this typically adopted, for instance, by Total Quality Management (TQM) and used to control risks within organizations. The successful operation of such procedures is often initiative of management commitment to continuous improvement in performance. The approach adopted by operators to the management of risks associated with corrosion and/or installation integrity is generally similar to that adopted for management of safety risks, as required by legislation for the safety case.

Corrosion management also covers other integrity risks, including those from stress corrosion cracking, embitterment, erosion, etc., as well as "simple corrosion" (i.e. general, pitting and crevice corrosion). It was recognized that there are many ways to organize and operate successful corrosion management systems, each of which is asset specific depending on factors such as design, stage in life cycle, process conditions and operational history. The corrosion policy provides a structured framework for identification of risks associated with corrosion, and the development and operation of suitable risk control measures. Where, the corrosion management framework is shown in Figure 3.

A general corrosion management system has been outline provides a progressive framework that is compatible with the requirements of a geothermal industry safety management system concerned with ensuring the integrity of topside processing equipment. That is, employers should have effective plans and organizations to control, monitor and review preventative and protective measures to secure the health and safety of employees. Where, the successful of Corrosion Management is depends on the overall policies adopted by an organization; the role and responsibilities of manage, and staff within the organization including the development and maintenance of appropriate strategies; the development of plans and procedures, plus the means of implementation of various corrosion control measures; the methods adopted for performance measurement of the system against predetermined criteria; the use of systematic and regular reviews of system performance; and the use of periodic audits of the management and monitoring systems.

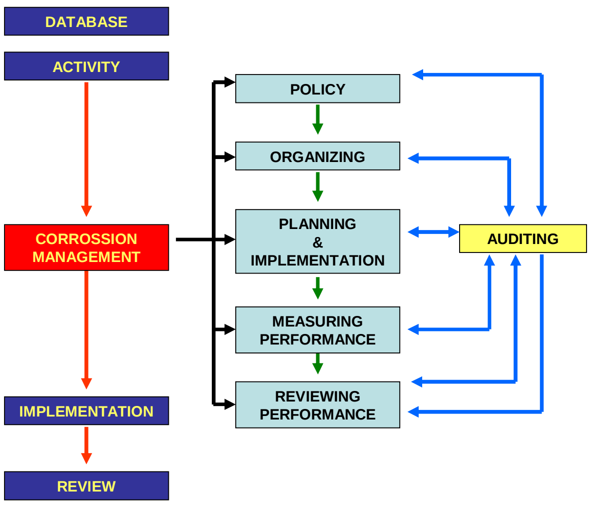

Figure 3: Corrosion Management Framework

3.2 Risk Management Analysis

Risk Management Analysis (RMA) is a technique to determine and to find causes of risk, mainly to detect possibility of failure and damage in an operating system. This concept is integrates of Hazard Operability (HAZOP), Fault Tree Analysis, Failure Modes and Effect Analysis, Failure Modes and Effect Critically Analysis, Risk Based Inspection, Risk Centered Maintenance, Risk Based Maintenance. The international standards (such as API, API-STEP, EPA, OSHA, ISO 9000, ISO 1400, AISI, NACE, etc.) completed of the integration system. Actually, risk management analysis is a part of Integrated Asset Management System (IAMS) has been developed recently in Indonesia with the functions are:

- as the tools to obtain all data and information required for predicting risk potential nodes, which causes failure and damage;
- as the tools to investigate the possibility of risk and hazard occurred.

These results summarized on the techniques and methods to prevent and handle through the failure, damage, risk and hazard, including the advance action if the unlikely condition occurred by making predictions and scenarios to become Standard Operating Procedure. Where, area of interest on the utilization of Risk Management Analysis consists of: equipment design and operating system; equipment operation and all activities (including at time that the equipment deliver from the factory, installation until the equipment in full operation condition); conducted maintenance process (including monitoring, inspection, special maintenance, advance maintenance, replace the equipment, installing the new equipment, auditing and recommendations).

The objective of Risk Management Analysis activity is to obtain the integrated system, start from design, operational, maintenance, prevent and handling of a potential risk and hazard, and the action that should be take if the unlikely condition occurred. This Risk Management Analysis activity will perform on the scenarios based on initial and advance predictions as the results from off-site and on-site inspections. Beside that, Risk Management Analysis also identified the problems at the operation process to obtain risk potential nodes which will be occurred risk and hazardous. These risk potential nodes including human and their activities; equipments, material, process/operation and maintenance including technology; and environment. The risk management analysis framework is shown in Figure 4, respectively.

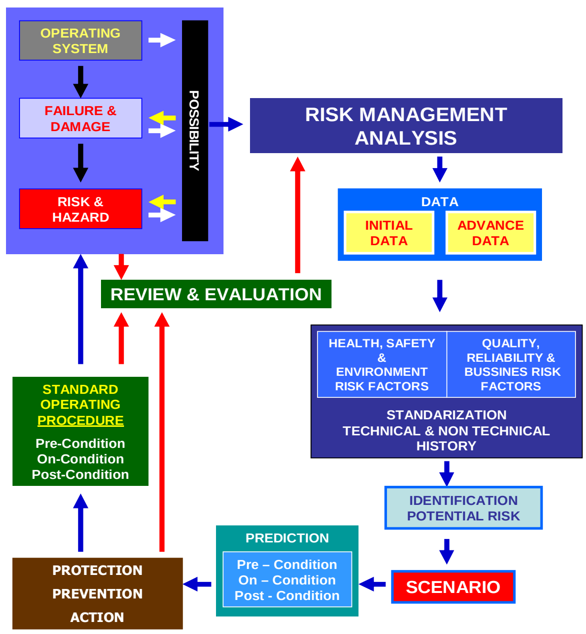

Figure 4: Risk Management Analysis Framework

3.2.1 Data

Data can be determine into two types, initial data and advance data. Initial data or initial design obtained based on the specification, material choices, standard and procedure of the fabrication and equipment function. Re-checking of obtained data required and compare with the International or national standard, quality and reliability, HS&E,

technical and non-technical factors, and the history of the equipment. Furthermore, make a possibilities of occurring failure and damage, also the possibility which will causes a risk and hazard, including prevent and handling, and the actions if the unlike conditions happened. All the process results performed on the scenarios as an initial prediction, including risk potential nodes mapping together with preventing and handling actions. Furthermore, the advance data obtained by off-site and on-site techniques. Off-site data is a data obtain based on the reports (daily, monthly, annual, etc) without doing inspection in the fields where the equipment operated. From of the some anomaly found, can get the solution to prevent and handling if the risk and hazard occurred, of course, with conducting some tests and observation. This data is quite representative, but not too accurate due to field condition that has dynamic property. While, On-site data is the same with off-site data, but the different is we conducted inspection in the field. Time and cost required for inspection are more expensive than off-site data, but the accuracy gave a positive indication than the off-site data.

3.2.2 Failure, Damage and Identification of Risk Potential Nodes

Failure is malfunctions/un-working/un-operation of a system as well as due to certain causes. Failure can causes by: design and construction failure, material and fabrication failure, installation or set-up failure, maintenance failure, observation during operation failure, human resources failure, and situation and condition predictions failure. Furthermore, damage is defined as malfunctions/un-working/un-operation of a system, which will affect to overall system. Damage can causes by physical, mechanical, chemical, and biological damages. While, identification of risk potential is also observe all the data to obtain the accurate of risk potential nodes based on: equipment identification, identification of the place assembling located, identification of the facility/equipment relate with the equipment which will installed, identification of assembling/installation, identification of operating procedure and maintenance, and identification of procedures and inspection equipment and monitoring.

3.2.3 Scenarios

Scenarios which made could be divided into two types, i.e., initial scenario with initial prediction, based on initial data; and advance scenario with advance prediction, this scenario will use initial scenario basis and will add with initial data based on offsite/onsite inspection and monitoring. These scenarios was made based on the possibilities of risk occurred, hazard, failure and damage of the operational, so, with this scenarios we could be knew the preventing and handling technique as early as possible. The objectives of scenarios made into prevent and handling of risks, are cost and time efficiency which required for inspection, review, recommendation and re-auditing; minimize risk of operational failure and damage; to make a program if the hazard occurred, as a basic for SOP making; maintenance production continuity; prevention and handling of risk and hazard early, quickly and accurately; and maintenance the equipment life cycle and facilities. This prediction will used to make a scenario to achieve an effective and optimally action of prevention and handling problems. Beside that, the scenario will be made if the hazard occurred and to make an actions later, including investigating and determination of material loss, immaterial, management, human resources, technology, environment and financing. These scenario could be divide into three stages, are Pre-condition, On-condition and Post-condition. The scenarios that have been made must be combines between risk potential identification methods with the other factors (HS&E, Quality, Technique/Non-Technique, Prevention and Handling). The scenario usage by the company must be follows to the international standard.

4. STRATEGY DEVELOPMENT

Processing of corrosive and toxic produced fluids is a major hazard on geothermal installations. Acidic carbon dioxide and hydrogen sulfide gasses when dissolved in produced steam can give rise significant corrosive damage unless their action is monitored, controlled and managed. Note that few organizations have a written corrosion policy but by interference it is built into the safety and environmental policies. The effectiveness of any policy depends on the leadership, commitment and involvement of managers and senior staff. Safety is of concern to everyone; employer, employee and contractor. Corrosion should also be of concern. A positive health and safety culture and corrosion culture means less risk to individuals and less damage to the integrity of a facility. The four "Cs" of a positive culture are ***competence, control, co-operation and communication***. These are vital for management of a complex subject area, such as corrosion. The crossword schematic of corrosion management technology is shown in Figure 5.

Planning is vital for success and is based on long term strategies and objectives. Identification of hazards, assessment of risks and agreement on requirements is basic to the management process. Implementation often makes use of company guidelines, industry codes and international standard; checks will be required to determine whether they are appropriate and effective. Selection of monitoring and inspection procedures; including agreement of a standardized approach to what is acceptable, when equipment judged to be out of condition and, if dangerous, what are the actions required. Three points should be considered regarding acceptable criteria there are must be measurable, achievable and realistic. The strategy planning schematic and strategy development of overall assessment and project based on corrosion management technology are shown in Figure 6 and Figure 7, respectively.

Success can only be demonstrated by use of monitored data that is converted into management information. Conversely, poor management decisions are often the result of inadequate data. There is a need to identify the current position within a facility (fitness for use of materials and equipment plus the management system in place) and then undertake prediction of the future situation (risk based/condition based trending and "what if" scenarios) in order to establish what, if anything, is required to achieve improvements. A low maintenance or repair rate over a period of years is neither a guarantee of effective control of corrosion rates nor that failures will not occur in the future. Only by regular measurements can it be demonstrated that the corrosion policies and corrosion control procedures are effective. Monitoring of plants, the control procedures and personnel is a management responsibility. Success must be judged against pre-determined performance requirements or standards (acceptable metal loss per year, achievement of inhibitor availability criteria). Two types of monitoring system are required, i.e:

a. Active monitoring uses regular checks and inspections, or even continuous evaluations, to ensure that agreed criteria are being met. It makes measurements before things go wrong. It predicts when a system is not working, monitors the condition and, by means of feed-back reporting and control procedures, prevents damage. Performance standards relevant to corrosion management would include minimum allowable wall thickness, remnant life assessment, verification of acceptable corrosion rates, ensuring inhibitor availability, obtaining and logging of appropriate process data plus recording and trending of steam leak data. A further purpose is to measure success and reinforce positive achievement by rewarding good work but not to penalize failure.

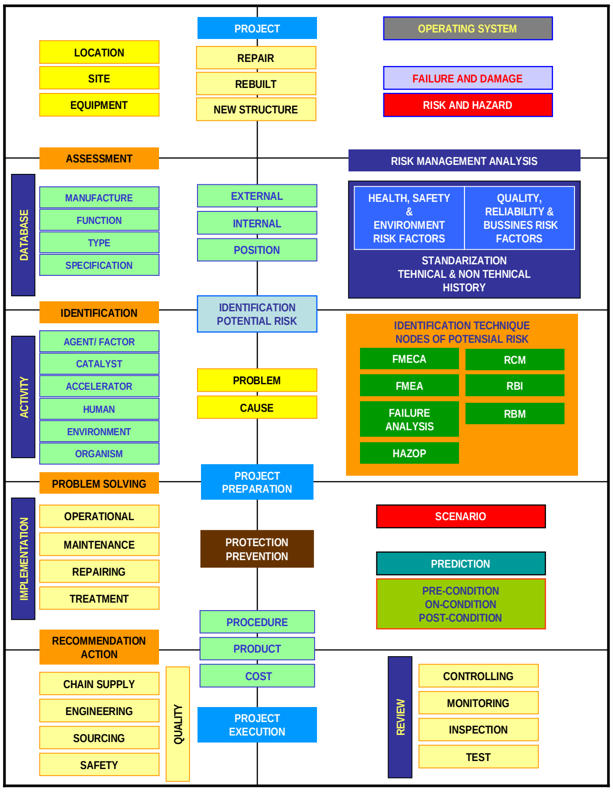

Figure 5: Crossword Schematic of Corrosion Management Technology

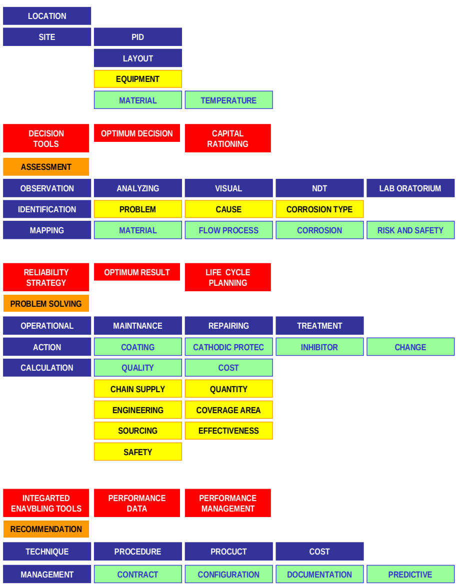

Figure 6: Strategy Planning Schematic of Corrosion Management Technology

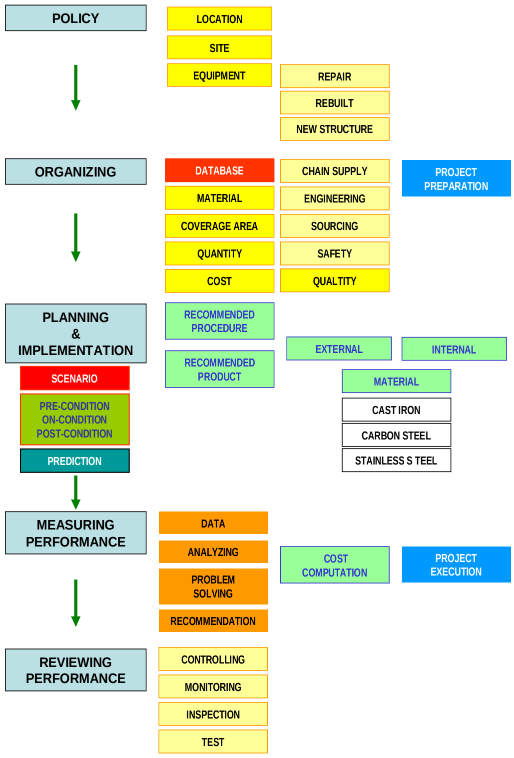

Figure 7: Strategy Development of Corrosion Management Technology

b. Reactive monitoring involves the recording of after failure examinations, repair incidents and other evidence of deficient corrosion control performance, including cases of unacceptable damage or near misses, mal-operation, unexpected events and inadequate procedures. Substandard performance must be investigated and reported if improvements are to be made and mistakes eliminated. However, the use of appropriate procedures and a suitable data base, which allows easy access for investigation and analysis, for development of a response system, for problem reviews and actions, is essential.

Both monitoring systems require supporting procedures that not only investigate causes of substantial performance but also recommend improvements in procedures. The essentials from a management control audit are not only the technical issues but the procedures, organizational structures and individual responsibilities that also require verification. Information based on data from pro-active and re-active monitoring systems should be evaluated promptly to identify the causes and both immediate risks and longer term risks in order to ensure prompt remedial action were necessary. This will require a system where the information can be referred to the management level with the authority to initiate the remedial actions including any organizational and policy changes. Detail of corrosion monitoring techniques (direct and indirect techniques) is shown in Table B (see Appendix).

Monitoring and inspection provide evidence of compliance to agreed criteria, whilst reviews enable improvements to be made. There must be mechanisms in place to ensure that reports from reviews and audits result in actions. There is also need to improve communication between operational personnel and design teams to ensure feed-back of operational experience into new designs. Monitoring to ensure achievement of pre-determined criteria can be at various levels. It can mean monitoring the performance of the management system, the performance of groups or individuals within the system, the performance of physical inspection techniques used to assess asset condition or performance of corrosion monitoring techniques employed for inhibitor control. Achieving success needs both the management structures and the data gathering or interpretation systems to be in place in order to minimize corrosion and safety risks.

In geothermal installations, a major concern is the prevention of major incidents resulting from failure of safety-critical elements. Addressing this hazard requires an understanding of failure modes and use of industry standard procedures for the assessment and control of risks. The failure mode is a key input into the methodology employed to assess engineering risk or criticality. A formal engineering risk evaluation of equipment is referred to as a Failure Mode, Effect and Criticality Analysis (FMECA), that ranks perceived risk in order of seriousness:

Criticality (Risk) = Effect (Consequences) x Mode (Probable frequency) (1)

where:

a. Failure criticality – potential failures are examined to predict the severity of each failure effect in terms of safety, decreased performance, total loss of function and environmental hazards.
b. Failure effect – potential failures assessed to determine probable effects on process performance and the effects of components on each other.
c. Failure mode – anticipated operational conditions used to identify most probable failure modes, the damage mechanisms and likely locations.

The analysis determines the probability of each failure mode occurring (P), the seriousness (consequences) of the failure (S) and also include the difficulty of detecting the failure (D). The criticality index (C) provides a numerical that enables management to focus on audit procedures (appropriate maintenance and corrosion control strategies, including inspection activities) on items of plant, or processes that are deemed to have either high/unacceptable risks or low/acceptable risks.

$$\boldsymbol{C = P \times S \times D} \quad (2)$$

Criticality/risk analysis can be carried out at all project stages: at design where the aim is to identify hazards and minimize risk by targeting corrosion mitigation procedures, and during operation where the aim is to focus inspection and monitoring on critical areas and to eliminate poor corrosion mitigation procedures. The criticality index is shown in Table 1.

Table 1: Criticality Index

Probability (P)	low chance of occurrence------almost certain to occur									
Seriousness (S)	not serious, minor nuisance----total failure, safety hazard									
Detection (D)	easily detected--------------------unlikely to be detected									
Ranking Value (C)	1	2	3	4	5	6	7	8	9	10

A standard part of such evaluations is to use a matrix display to highlight or quantify the risks. Table 2 shows the operational criticality based on assessment of the failure probability, the effect of fluid corrosivity and likely failure rate, compared against the consequences of loss of plant integrity, operational pressures, volume and type of hydrocarbon. The criticality score or risk rating is then expressed numerically, as 1 to 5 (1 being highest, 5 being lowest, the latter is judged not critical for plant operation).

Table 2: Simplified Corrosion Risk

Criticality	**Consequence of Failure**		
Failure Probability	High	Medium	Low
High	1	2	3
Medium	2	3	4
Low	3	4	5

Identification and detection of hazards and assessing risks due to corrosion problem is a fundamental for any geothermal management process. Summary of corrosion detection NDE/NDI/NDT technologies is shown in Table C (see Appendix). A hazard has a potential to cause harm or damage, and a risk is the combination of the severity of the effect (the consequences) and the likelihood of it happening (damage mode and probably frequency). Geothermal industrial corrosion risk management based on the corrosion management technology is a careful examination of potential hazards that may affect the operation of a business; these may be risks associated with the safety and integrity of physical assets, risk to environment, financial risks from various decisions and also risks from corrosion or poor corrosion mitigation procedures. At its simplest it is common sense approach that provides a means of checking what often good existing practice.

For example, in geothermal industry produced steams and/or fluids are therefore a hazard. Some steams or fluids also contain hydrogen sulphide, this toxic gas is present in the reservoir, either naturally because of the chemistry of the strata or can be a result of biological contamination. Such steams or fluids are therefore hazardous with the potential to cause death and injury to personnel. Loss of containment can also result in damage to the environment. Beside that, most geothermal processing equipments are fabricated from carbon-manganese steel. This is an economic choice, based on lifecycle costing at the design stage of a project. Use of C-Mn steels means potential hazards are present due to internal corrosion damage from produced steams or fluids that contain acidic gasses, carbon dioxide and hydrogen sulphide. In addition, corrosion related failures can result in significant loss of production, as well as increased costs for maintenance, repair or replacement. Management of corrosion is therefore a major driver for safety, environmental and economic issues within the geothermal industry.

The main functions of Risk Management Analysis are to identify potential risk nodes and as decision tool to predict the possibility of failure, damage and hazard, while, corrosion management has function as an Integrated Enabling Tools. When Risk Management Analysis and Corrosion Management became an integrated system into Corrosion Management Technology, we found an advance corrosion management system in one integrity system and then can be implemented to computerized design, operation and maintenance management system of geothermal industry in the central admin processing unit is shown in Figure 8.

The strategy design, operation and maintenance management system can be build using real time data monitoring and will storage into database as advance data to completed initial data. Data can be transfer from field through internet, intranet, GPS, Satellite, radio and others system communications that suitable with server of the central admin. With real time system, the central admin can then be determines and predicts the problems that may occur based on the anomalies and field situation as online – offsite system. If the anomalies deviation is big enough, it is possible that we have to send a team to the field to make an inspection as online – onsite system to see the real problem. Thus, the team monitoring which integrated with online – offsite and online – onsite systems to the company has several advantages such as can reduce the cost of operation, increase the value of safety, to keep performance and efficient of operation system, to optimize production, to keep environment, and effective inspection and monitoring systems. The strategy development planning of overall assessment and project of geothermal installations based on corrosion management technology is shown in Figure 9, respectively.

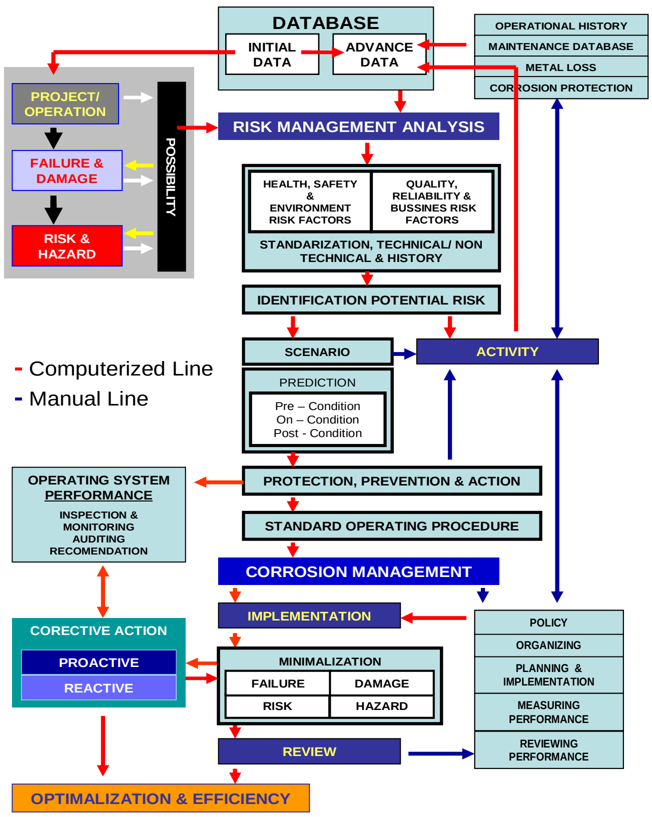

Figure 8: Strategy Management System of Corrosion Management Technology

Furthermore, in order strategy development of the corrosion management technology on geothermal industry, a good corrosion control/mitigation to ensure adequate safety procedures requires good design. The continuing review of safety-critical elements as part of the safety case should provide a driver for improvement of feedback from the field into new design. These include HAZOP studies and engineering reviews, hence introduction of corrosion related safety checks at these stages of the design process would be recommended. These means of conducting inspections and corrosion monitoring, including provision of adequate access for personnel, monitoring instrumentation and inspection equipment is often crucial. The use of strategy development of corrosion management technology during design and implementation would assist in the overall corrosion management systems, where the target of corrosion management technology to solve the corrosion problem on the geothermal industry, especially on the geothermal installations is shown in Figure 10.

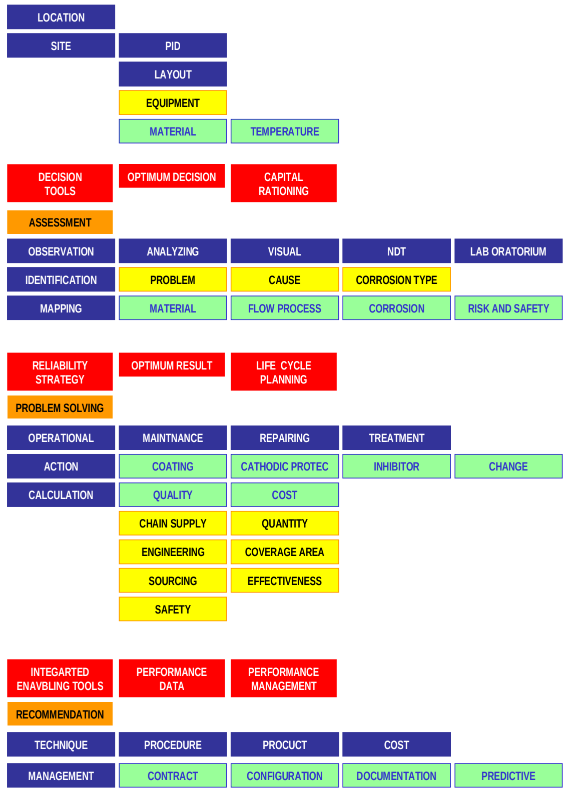

Figure 9: Strategy Development Planning of Overall Assessment and Project of Geothermal Installations Based on Corrosion Management Technology

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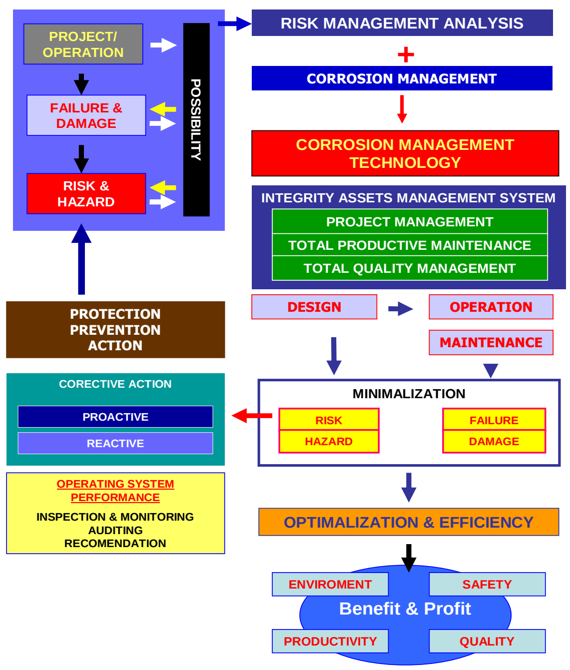

Figure 10: Target of Strategy Development of Corrosion Management Technology in Geothermal Industry

4. CONCLUSIONS

1. Corrosion management technology is a part of the overall management system which is concerned with the development, implementation, review and maintenance of the corrosion policy.
2. A corrosion policy includes establishment of organizational structures with defined responsibilities, reporting routes, practices, procedures, processes and resources. The effectiveness of any policy depends on the leadership, commitment and involvement of managers and the staff to be implemented operationally in the fields.
3. Corrosion management technology has a key role to play in ensuring asset integrity, control of system and safety in the geothermal industry. This approach imposes a formal structure to the concept of corrosion management and risk management analysis.
4. The utilization of corrosion management technology approach during design and implementation would assist in the overall corrosion management systems.
5. Successful implementation of strategy development of corrosion management technology also influences of the technically and economic outcomes by ensuring cost effective selection of materials, treatments, coatings, cathodic protection systems, appropriate design, effective inspection and monitoring systems.

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APPENDIX

Table A: Forms of Corrosion – ASM Classifications

General Corrosion	Localized Corrosion	Metallurgically Influenced Corrosion	Mechanically Assisted Degradation	Environmentally Induced Cracking
Corrosive attack dominated by uniform thinning • Atmospheric Corrosion • Galvanic Corrosion • Stray-Current Corrosion • General Biological Corrosion • Molten Salt Corrosion • Corrosion in Liquid Metals • High-Temperature Corrosion	High rates of metal penetration at specific sites • Crevice Corrosion • Filiform Corrosion • Pitting Corrosion • Localized Corrosion • Biological Corrosion	Affected by alloy chemistry and heat treatment • Intergranular Corrosion • Dealloying Corrosion	Corrosion with a mechanical component • Erosion Corrosion • Fretting Corrosion • Cavitation and Water Drop Impingement • Corrosion Fatigue	Cracking produced by corrosion, in the presence of stress • Stress-Corrosion Cracking (SCC) • Hydrogen Damage • Liquid Metal Embrittlement • Solid Metal Induced Embrittlement

Table B: Corrosion Monitoring Techniques

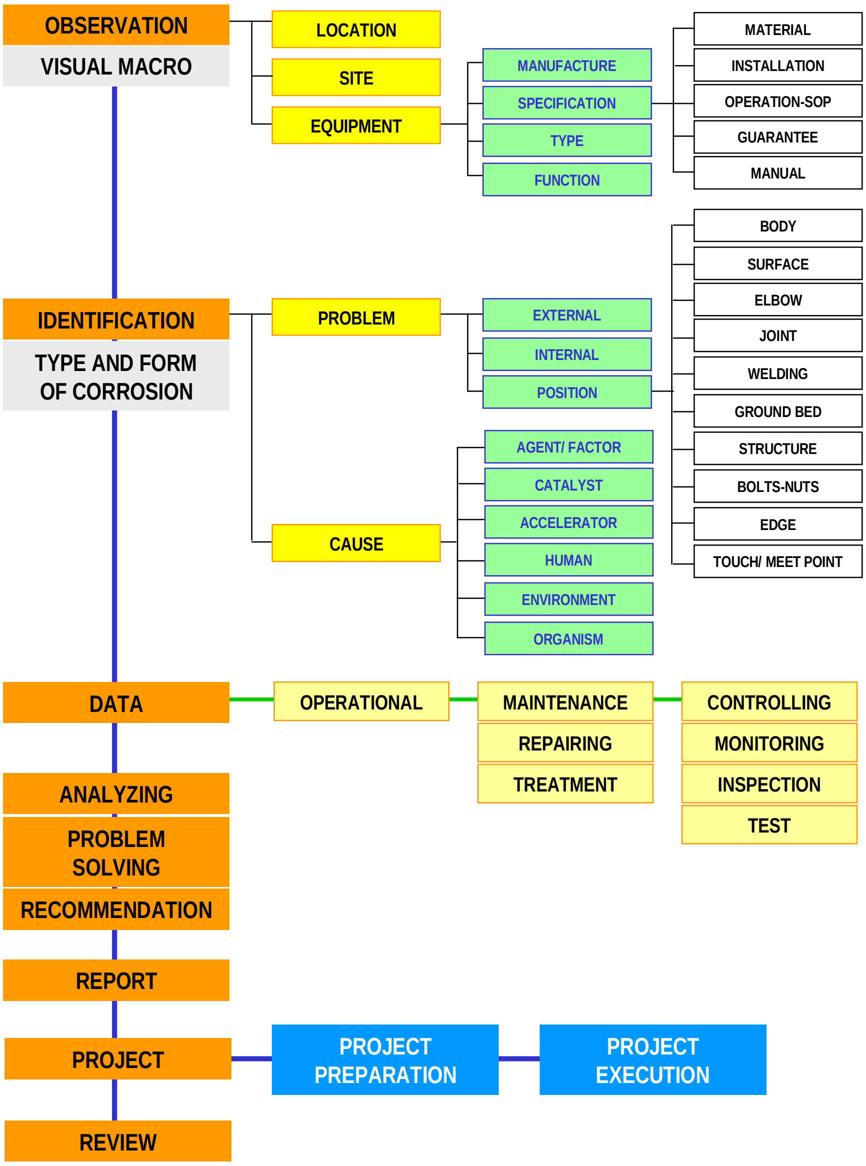
Direct Techniques	Indirect Techniques
• Corrosion Coupons ***(intrusive)*** • Electrical Resistance (ER) ***(intrusive)*** • Inductive Resistance Probes ***(intrusive)*** • Linear Polarization Resistance (LPR) ***(intrusive)*** • Electrochemical Impedance Spectroscopy (EIS) ***(intrusive)*** • Harmonic Analysis ***(intrusive)*** • Electrochemical Noise (EN) ***(intrusive)*** • Zero Resistance Ammetry (ZRA) ***(intrusive)*** • Potentiodynamic Polarization ***(intrusive)*** • Thin Layer Activation (TLA) and Gamma Radiography ***(intrusive or non-intrusive)*** • Electrical Field Signature Method (EFSM) ***(non-intrusive)*** • Acoustic Emission (AE) ***(non-intrusive)***	• Corrosion Potential ***(non-intrusive)*** • Hydrogen Monitoring ***(non-intrusive)*** • Chemical Analyses

Table C: Summary of Corrosion Detection NDE/NDI/NDT Technologies

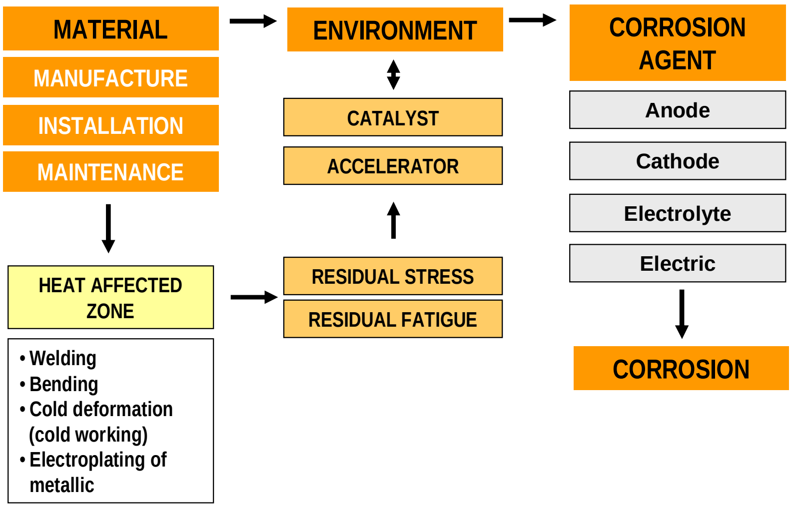
Technology	Advantages	Disadvantages	Primarily Detects
Visual	• Relatively inexpensive • Large area coverage • Portability	• Highly subjective • Measurements not precise • Limited to surface inspection • Labor intensive	Surface, exfoliation, pitting and intergranular corrosion
Enhanced Visual	• Large area coverage • Very fast • Very sensitive to lap joint corrosion • Multi-layer	• Quantification • Difficult • Subjective – requires experience • Requires surface preparation	Same as visual except enhanced through magnification or accessibility
Eddy Current	• Relatively Inexpensive • Good resolution • Multiple layer capability • Portability	• Low throughput • Interpretation of output • Operator training • Human factors (tedium)	Surface and subsurface flaws such as cracks, exfoliation corrosion around fasteners and corrosion thinning
Ultrasonic	• Good resolution • Can detect material loss and thickness	• Single-sided • Requires couplant • Cannot assess multiple layers • Low throughput	Corrosion loss and delaminations, voids in laminated structures
Radiography	• Best resolution (~1%) • Image Interpretation	• Expensive • Radiation safety • Bulky equipment	Surface and subsurface corrosion flaws
Thermography	• Large area scan • Relatively high throughput • Macro view of structures	• Complex equipment • Layered structures are a problem • Precision of measurements	Surface corrosion

Robotics and Automation	• Potential productivity improvements	• Quality assurance • Reliability	Various

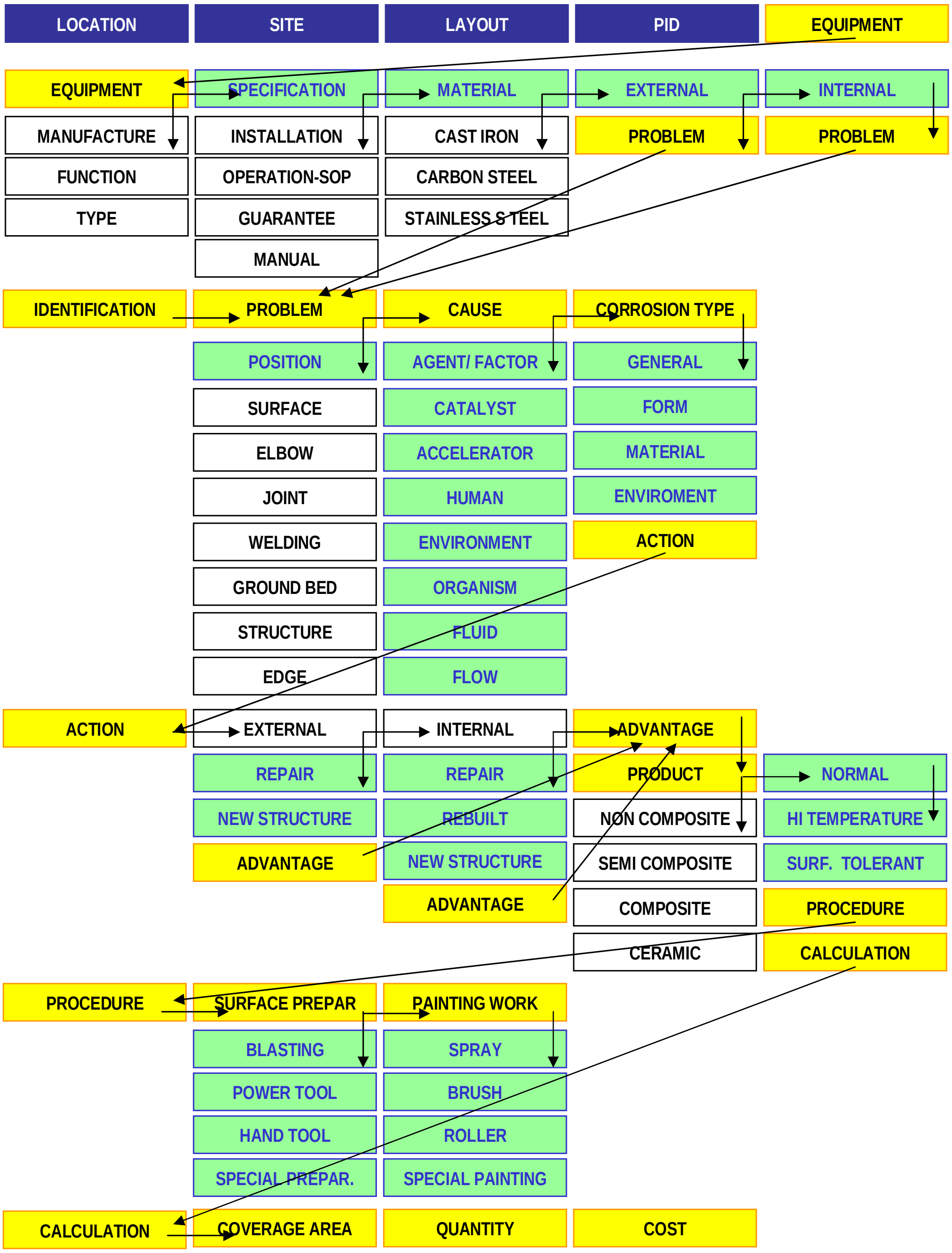
STRATEGY MECHANISM - STEP 1
PLANNING



STRATEGY MECHANISM - STEP 2
OBSERVATION RESULT



STRATEGY MECHANISM - STEP 3
PROJECT FORMULATION USING PROTECTIVE COATING


LOCATION
SITE
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EQUIPMENT
EQUIPMENT
SPECIFICATION
MATERIAL
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MANUFACTURE
INSTALLATION
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PROBLEM
PROBLEM
FUNCTION
OPERATION-SOP
CARBON STEEL
TYPE
GUARANTEE
STAINLESS STEEL
MANUAL
IDENTIFICATION
PROBLEM
CAUSE
CORROSION TYPE
POSITION
AGENT/ FACTOR
GENERAL
SURFACE
CATALYST
FORM
ELBOW
ACCELERATOR
MATERIAL
JOINT
HUMAN
ENVIROMENT
WELDING
ENVIRONMENT
ACTION
GROUND BED
ORGANISM
STRUCTURE
FLUID
EDGE
FLOW
ACTION
EXTERNAL
INTERNAL
ADVANTAGE
REPAIR
REPAIR
PRODUCT
NORMAL
NEW STRUCTURE
REBUILT
NON COMPOSITE
HI TEMPERATURE
ADVANTAGE
NEW STRUCTURE
SEMI COMPOSITE
SURF. TOLERANT
ADVANTAGE
COMPOSITE
PROCEDURE
CERAMIC
CALCULATION
PROCEDURE
SURFACE PREPAR
PAINTING WORK
BLASTING
SPRAY
POWER TOOL
BRUSH
HAND TOOL
ROLLER
SPECIAL PREPAR.
SPECIAL PAINTING
CALCULATION
COVERAGE AREA
QUANTITY
COST